A Novel Wireless Mobile Platform to Locate and Gather Data From Optical Fiber Sensors Integrated Into a WSN

Bochao Zhou, Shuo Yang, Tong Sun, and Kenneth T. V. Grattan

Abstract— **This paper presents a novel design for a wireless mobile platform to locate and gather data from different types of optical fiber sensors, thereby enabling the more effective integration of a number of such optical fiber sensors with an advanced mobile wireless sensor network (WSN). This then more readily permits potential applications, such as monitoring in remote and harsh environments and tracking, exploiting fully the combined advantages offered both by the mobile WSN and the advanced optical fiber sensing technologies. The platform which was designed and implemented consists of an optical fiber sensor module and a smart mobile WSN module, which shows important advantages for mobile sensing and tracking and mesh networking. In this paper, a fiber Bragg grating-based temperature sensor and an intrinsic pH optical fiber sensor were specially designed and integrated successfully into the optical fiber sensor module as an exemplar to investigate the performance of the integrated system based on the mobile WSN platform. The positive experimental results obtained have confirmed the functionality of the platform designed and demonstrated its capacity for real-time optical fiber sensor data monitoring, processing, and wireless transmission. The successful creation of this type of wireless mobile platform with optical fiber sensors can thus be expected to make an important impact on a number of sectors, where either conventional optical sensor designs or WSNs alone cannot meet the systems requirements.**

Index Terms— **Wireless sensor network, optical fiber sensors, pH sensor, mobile control, RSSI localization.**

I. Introduction

OPTICAL fiber sensors have wide-ranging potential in sensing and measurement and have been able to demonstrate a number of advantages over conventional sensor technology for a variety of applications [1]. However such optical fibre sensor systems are often used as ‘stand-alone’ devices in pre-defined positions: thus there is a need for extensive lengths of fibre optic cable connecting all the sensors as an optical fibre network and in many circumstances dealing with this cabling can be a problem. Wireless sensor networks (WSNs) have gained considerable, indeed world-wide attention in recent years and provide an effective means for acquiring information on parameters such as temperature, pressure, acceleration, vibration and the measurement of chemical species, usually based on exploiting conventional Micro-Electro-Mechanical System (MEMS) sensors [2]. To date, although there have been some reports of the integration of optical sensors into a WSN platform e.g. by O’Connell et al [3], most WSN systems do not use optical fibre sensors and thus fail to benefit from the synergy of both technologies – accessing the advantages seen in the use of a wireless sensor networks and at the same time coupling these to the benefits of the advanced design and the significant capabilities of optical fibre sensors. In addition, mobile robots have been used widely to perform a wide range of critical tasks such as exploration, search and rescue operations, and reconnaissance [4]. In recent years, extensive research has been undertaken in the field of mobile network and robot control [5], [6]. All of these offer the potential to integrate mobile robots with a generic WSN platform, thus to form a mobile WSN platform to overcome the limitation arising from using a static WSN platform. Here this approach is coupled to an advanced optical sensor system, offering the flexibility to address various sensing needs arising from different environmental contexts – from dangerous or hazardous scenarios where there are radioactive, chemical, and other industrial-based issues to the more routine and mundane. However in all of these, high quality measurement is essential.

Based on the above requirements and previous research by the authors [7], in this study a mobile WSN platform has been designed and implemented to enable the seamless integration of both physical and chemical optical fibre sensors, allowing access to the advantages from the advanced design of the optical fibre sensors to be coupled with the benefits of the mobility offered by the mobile robots. For this demonstration, an optical fibre Bragg grating (FBG)-based temperature sensor and an intrinsic pH optical fibre sensor developed by some of the authors were specifically chosen to be integrated into the platform, (both offering low power consumption) and

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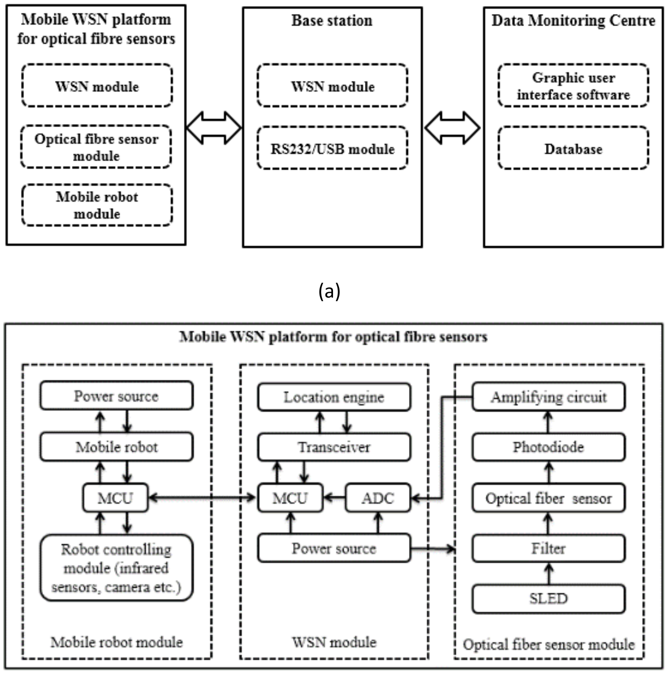


(b)

Fig. 1. (a) System architecture of the WSN platform for the optical fiber sensors. (b) Schematic of mobile WSN platform for the optical fibre sensors.

are used further to evaluate the functionality of the mobile WSN platform created while supporting Graphical User Interface (GUI) software, where robot control algorithms have been developed for sensor data monitoring and mobile robot controlling. The system is described and results of tests and evaluation carried out are reported.

II. Platform Design and Implementation

A. System Overview and Mobile WSN Platform

The system designed comprises three key components: the mobile WSN platform, the base station and the data monitoring centre, all of which is illustrated schematically in Figure 1(a). Each mobile WSN platform was integrated with a WSN module, coupled to computing and group communication functionalities allowing for data transmission via multi-hop routing, an optical fibre sensor module with its in-build sensing capabilities and a mobile robot module which enables mobility of the platform and thus allowing the flexible in the sensing performance. The base station was used to collect the sensor data and then to transmit these data to a data monitoring centre for further recording, processing and display, which is based on Graphic User Interface (GUI) software and database system.

Figure 1(b) shows the detailed design of the mobile WSN platform. The platform contained three key components: the WSN module comprising a transceiver (CC2531, Texas Instruments Inc.) with a build-in location engine; an MCU (MSP430F5437, Texas Instruments Inc.); an analogue-to-digital converter (ADC); and a power source for data processing and network communication. The mobile robot module used includes an inexpensive 'off-the-shelf' robot from Active Robots Ltd integrated with a robot controlling module (video camera module etc.) and an optical fibre sensor module.

B. Optical Fibre Sensor Designs

In this study, two sensors system were specially designed and implemented, these being representative devices from both physical and chemical optical fibre sensors, to test and evaluate the functionality of the mobile WSN platform created in a comprehensive way.

1) Sensor 1 – Physical Sensor – Fibre Bragg Grating (FBG)-Based Sensor System: The development of the Fiber Bragg Grating (FBG) has been one of the milestone events in the history of optical communications and sensing [8] and provides an excellent basis for a sensor to be demonstrated in this way. The approach exploits the fact that a Fibre Bragg Grating (FBG) has an inherent sensitivity to strain and temperature, as it is well known that its resonance wavelength is dependent on the effective refractive index of the fibre core and the grating period [9]. Therefore such devices can be used for as the basis of sensor systems for the measurement of strain, temperature, or other measurands simply by monitoring the Bragg wavelength shift. The relationship governing the link between the wavelength shift and the measurand is given by:

$$\lambda_B = 2n_{eff}\Lambda \tag{1}$$

where λ_B is the Bragg wavelength, n_{eff} is the refractive index of the fibre core, and Λ is the Bragg grating period. The Bragg wavelength depends on the effective index of refraction of the core and the periodicity of the grating and both of these will be affected by changes in temperature [9]. For the measurement of a constant strain, the shift in the Bragg wavelength can be expressed as:

$$\Delta\lambda_B = \left[\frac{1}{\Lambda}\left(\frac{\partial\Lambda}{\partial T}\right) + \frac{1}{n_{eff}}\left(\frac{\partial n_{eff}}{\partial T}\right)\right]\lambda_B\Delta T \tag{2}$$

The first term relates to the thermal expansion of the fibre (typically 0.55×10^{-6} for silica fibre), and the second relates to the temperature dependence of the refractive index (approximately 8.6 pm/°C for Germania-doped, silica core fibre). It is clearly shown that the thermo-optic induced index change is the dominant effect. From Equation (2), the temperature sensitivity of a Bragg grating may vary between different materials. This forms the essence of the FBG-based sensor system used in this work which was configured here as a sensor only for temperature monitoring (with no external strain being applied to the fibre). Figure 2 shows the photograph to illustrate the complete FBG temperature sensor created for use with the WSN. The sensing probe, which contains a FBG at the tip, is protected by an aluminium tube which protects the sensor which was used in a series of experimental tests by subjecting the probe to various temperature conditions, as discussed.

2) Sensor 2 – Chemical Sensor – Intrinsic Optical Fibre pH Sensor System: The intrinsic optical fibre pH sensor used in this work has been designed and developed in concept by some of the authors [10] and developed and adapted

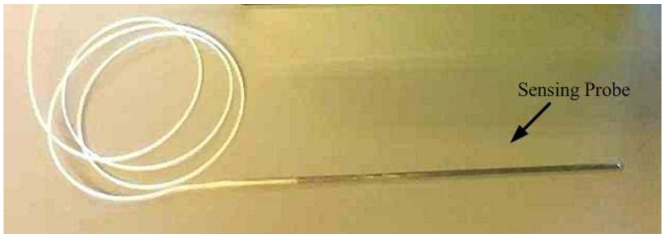
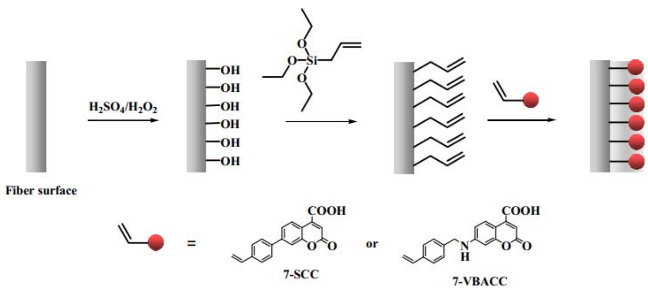


Fig. 2. Photograph of the FBG temperature sensor created for a WSN protected by an aluminium tube.



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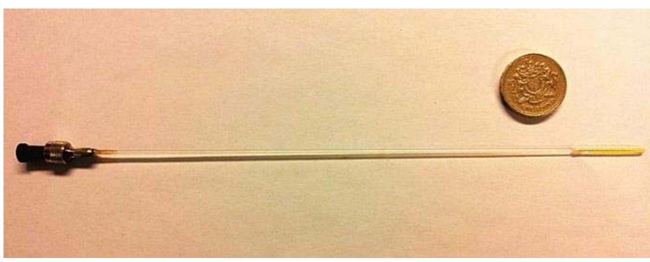
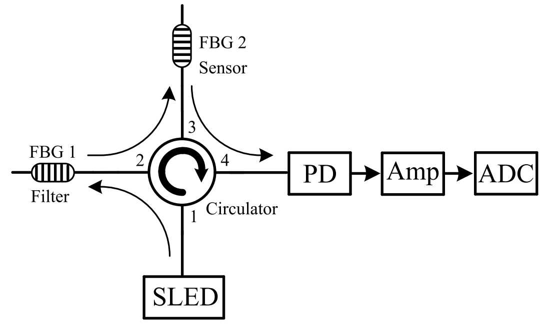


(b)

Fig. 3. (a) Schematic of the processes involved for preparation of the sensitive distal end of the pH sensor. (b) Photograph of the optical fiber pH sensor with the sensor material having been coated at the end surface of the fiber.

for use here. It was chosen as the sensor for use in this work not only as it is an effective exemplar of a sensor which can be effectively integrated into the mobile WSN platform but due to the importance of chemical sensors of this type for monitoring harsh working conditions, where conventional WSN sensors cannot work properly and thus integrating wireless technology with noise-immune fibre optics is particularly important.

As shown in Figure 3(a), the optical fibre pH sensor was created through a polymerization process, by covalent bonding of a novel fluorescent dye which was designed and synthesized specifically to provide an enhancement of the sensor sensitivity and stability, and integrated on the end surface of the optical fibre used. As reported previously [10], two different fluorescent dyes have been synthesized with their corresponding chemical structures also being shown in Figure 3(a). The sensor probe thus created and used in this work is shown in Figure 3(b). When the UV light from the light source was transmitted to the sensor probe through a 1×2 fibre coupler, the fluorescence signal generated by the pH sensor could be captured by a photodetector, which was connected to the other



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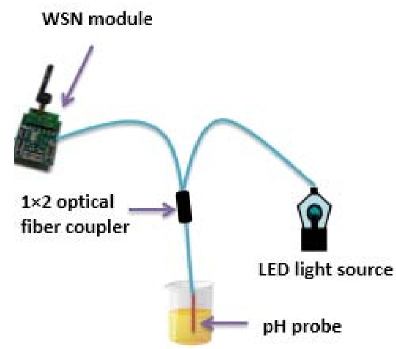


(b)

Fig. 4. (a) Schematic diagram of the FBG-based temperature sensor module; SLED – superluminescent LED; PD – photodetector; Amp – electronic amplifier; ADC-analogue-to-digital converter. (b) Schematic diagram of the intrinsic optical fibre pH sensor system.

end of the 1×2 coupler. As a result, fluorescence detection was used as the key optical transduction method, rather than the more conventional colorimetric method and this was employed in order to avoid interference from the light source and thus to achieve better system stability and sensitivity, making this also well suited for use with the WSN platform.

C. Optical Fibre Sensor Modules

The optical fibre sensor modules used, based on the above operation principles, are schematically illustrated in Figure 4.

The FBG-based temperature sensor module consists of a SLED light source (1550nm, Dense Light), a circulator (4 ports, JDS Fitel), an InGaAs photodiode (Thorlabs) and two Fibre Bragg Gratings (FBGs) written with the same central Bragg wavelength (1550nm). As shown in Figure 4(a), of these, FBG2 acts as a temperature sensor as its Bragg wavelength shifts as a function of temperature and FBG1, located at the other port of the circulator, is used as a reference where its surrounding temperature is fixed. This specific sensor design is aimed to minimize the power consumption, by using a low power light source (SLED) and a photodetector (PD), with a potential to share the same power module with the WSN. The SLED drive circuit includes a 100-mA constant current source and a high precision transimpedance amplifier (OPA380, Texas Instruments,) with an amplification gain of 107 V/W. The sensor signal obtained from FBG2, with reference to the signal from FBG1, is captured by a photodiode prior to being converted into digital signals using an analogue-to-digital converter (ADC). The overall size of the sensing module is 15cm×5.5 cm×4.5 cm, which has been carefully designed to be able to interface easily with the WSN module and robotic system.

As shown in Figure 4(b), the intrinsic optical fibre pH sensor system itself operated by coupling light from a UV light source to the sensor probe using a 1×2 fibre coupler, where the other end of the fibre coupler was connected to a mini-spectrometer or a photo-detector and through a filter. When the sensor probe was subjected to different solutions with different pH values, the fluorescence signal generated from the sensor probe was then modulated by the pH of the solution and the result captured by the mini-spectrometer or a photodetector used in the system. The intrinsic optical fibre pH sensor module comprised a LED light source (operating at 375 nm, Roithner Laser Technik), the optical fibre pH sensor developed in the laboratory, a 488 nm long-pass edge filter (Laser 2000 Ltd UK), a photodiode (Laser 2000 Ltd UK) and an amplifying circuit and data acquisition system.

D. Software and Location Algorithm Used

The ZigBee standard is specifically targeted for wireless sensor network applications for reliable, low-power and remote monitoring and control and thus was chosen for this application. Based on TI's industry-leading ZigBee protocol stack, Z-Stack, which is compliant with the ZigBee 2007 specification (ZigBee Pro.), was employed in this work for setting-up the wireless network supporting self-healing mesh networking. At the data monitoring centre, Graphical User Interface (GUI) software was designed and developed using Microsoft Visual Studio 2010 for device configuration, commissioning of networks, linking devices and data processing from the base station. The sensor data and location information collected by each mobile node in the WSN system could be displayed using the GUI software interface in either textual or graphical format, with the capabilities to retrieve historical data and playback. In the case of the robot control, the localization identification is of critical importance since the sensing data would be of limited value, should the location information were unknown for various applications [11]. In this work, a RSSI (Received Signal Strength Indicator) localization algorithm has been adopted and implemented in the robot controlling module and a video camera is also mounted on the robot to help with the navigation of the robot. The Location Engine which is integrated in the MCU of the targeted blind node enables the calculation of the distances between the blind node and the reference nodes through the broadcasting and receiving of related RF signals. All reference nodes have already been deployed and are assumed to know their own position. The known physical location of the static reference nodes combined with RSSI values obtained is able to provide the positional information for the targeted blind nodes.

An outline of this localization system as used in this work is shown in Figure 5. The targeted blind node is programmed to query the entire network periodically for the static locations

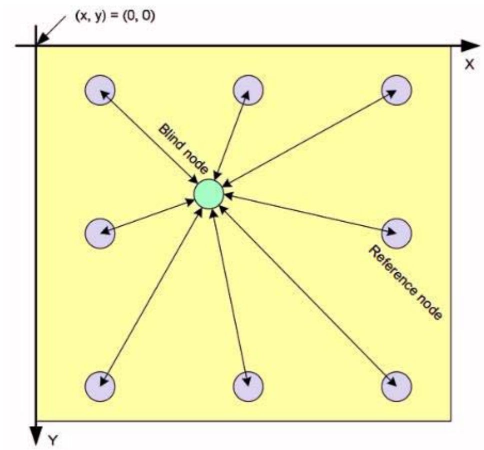


Fig. 5. Schematic diagram of the RSSI localization algorithm.

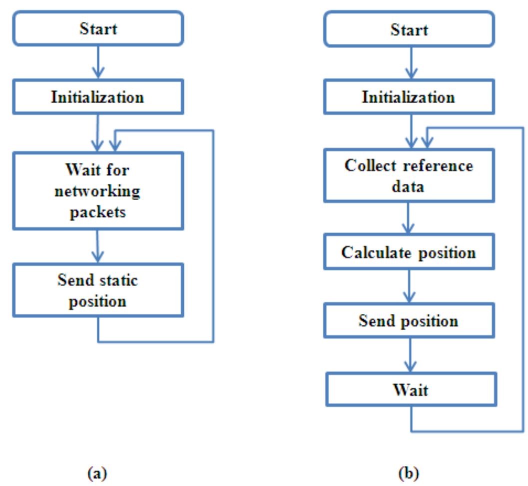


Fig. 6. Program flow of RSSI localization algorithm: (a) for reference node and (b) for blind node.

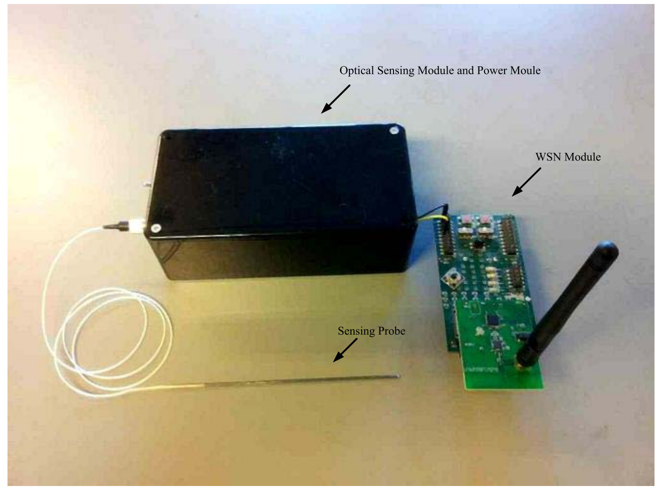
of all reference nodes that are within the transmission range and is configured to perform a position calculation. The programme flow chart is shown in Figure 6, but the procedure can be defined in three phases: broadcast, reference data collection and position calculation and reporting. The targeted blind node receives data packets from reference nodes and transforms the RSSI into distance values through measurement of the power strength of RF signal. By broadcasting and receiving data packets, the targeted blind node obtains the physical location information of the static reference nodes configured with X, Y and the distance values, which can be used to perform the position estimation calculation. The maximum-likelihood (ML) estimation is adopted in this study to calculate the estimated position of the targeted blind node by minimizing the differences between the measured and estimated distances [12].

III. Experimental Setup and Performance Evaluation

To evaluate the performance of the mobile WSN platform-based sensor system thus developed, two key, yet separate elements of the work were considered: the communication with the optical fibre sensors mounted on the robot through the WSN module and the robot location identification through the use of the localization algorithm and the analysis of the image information obtained from the video camera. The field test undertaken was designed to simulate a typical practical application scenario where the mobile robot is required to identify a point of interest in order for a measurement to be made, following which both the location information of the robot/sensor and the sensor data received at that specific position are required to be sent back to the base station for further signal analysis.

A. Experimental Setup for the Evaluation of the System

Figure 7(a) shows a complete optical fibre sensor system created for use with the mobile WSN, while the mobile robot module is illustrated in Figure 7(b).



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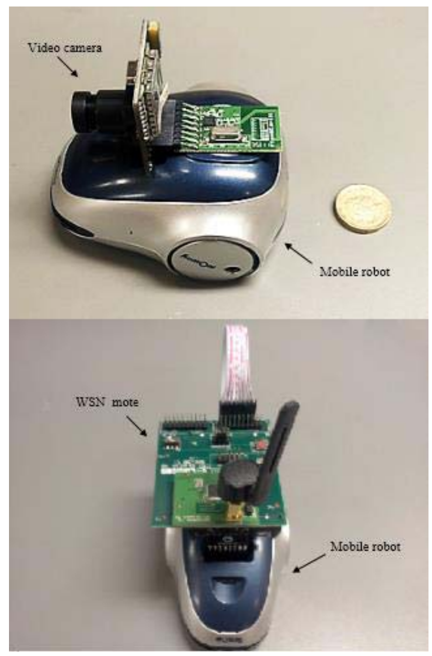


(b)

Fig. 7. Photographs of the integrated platform: (a) WSN module fully integrated with optical fibre sensor module and (b) mobile robot module integrated with a video camera and a WSN mote.

B. Evaluation of the Integrated Platform – the WSN Module Integrated With the Optical Fibre Sensor Module

Figure 8(a) shows the experimental data collected from the platform when the optical fibre sensor probe was placed in an environmental chamber for calibration, with the temperature varying from 20 °C to 80 °C. The ordinate shows the signal level received (recorded in volts for this figure and for Figure 8(b)). The dynamic response of the sensor obtained from the WSN platform is displayed in the data monitoring centre. It was noticeable that the signal intensity decreased as expected with the increase of temperature, as it varied from 20 °C to 80 °C.

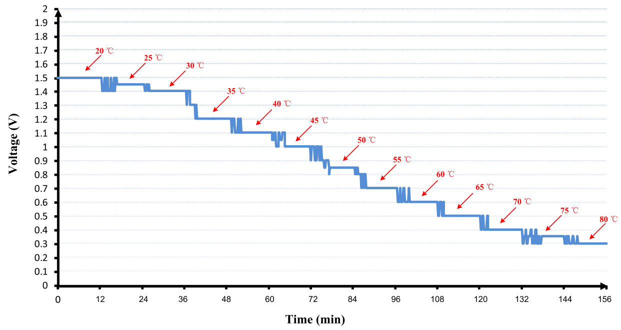
Figure. 8(b) shows the experimental data collected from the platform when the optical fibre sensor probe was inserted into various test solutions, in this test evaluation having been done over a series of pH values, showing a step change from pH 1 to 9. The dynamic response of the sensor was obtained from the data received at the monitoring centre. Initially, to 'zero' the system, the pH sensing probe was placed in an aqueous buffer solution of pH 1 for 5 minutes. It could be observed that the pH sensing probe has a fast response time ($\sim$70s) when moved between different solutions of different pH values and shows a stable output after the initial response period. It is noticeable that the signal intensity increases with the increase of pH of the solution used, seen when that varies from 1 to 9.

The results obtained show clearly the successful integration of the optical fibre sensors into the mobile WSN platform through acceptable measurements being made of both (a) physical and (b) chemical parameters.

C. Field Test of the Mobile Robot

The field test was designed to simulate typical practical application scenarios where the mobile robot is sent to a point of interest in order for a measurement to be made and this is reported back to the investigators, giving both the location of the robot/sensor and the sensor data received at that specific position. To evaluate the performance of the robot control based on the RSSI localization algorithm, a practical test was set up as shown in Figure 9. Four Reference Nodes, with known (X, Y) positions, were deployed in the network and indicated as the yellow circles in the pictures of practical experimental environment, as illustrated in Figure 9(b) and (d). Figure 9(a) illustrates the GUI software at data monitoring centre designed for (b) and (c) for (d).

The targeted blind node was configured periodically to query the entire network for the (X, Y) positions of all reference nodes. The procedure could then be defined as discussed as three phases: broadcast, data collection, and position calculation. In the broadcast phase, the targeted blind node sends out a one-hop broadcast to learn the network address of all reference nodes that are within radio range.



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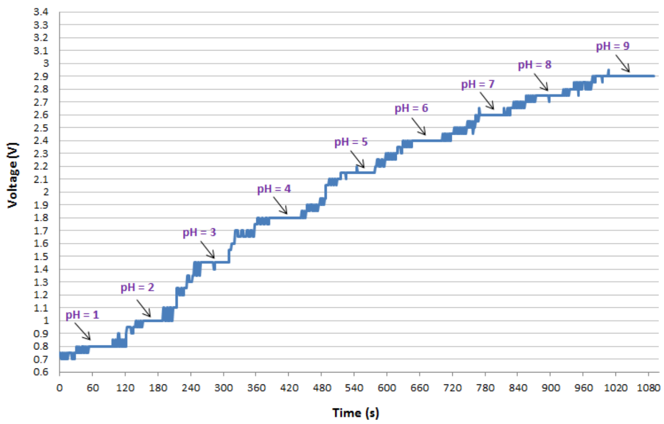

(b)

Fig. 8. (a) Dynamic response of the WSN platform integrated with the optical fiber temperature sensor (FBG2) when it was subjected to different temperature conditions. (b) Dynamic response of the WSN platform when the intrinsic optical fiber pH sensor was subjected to different pH conditions showing the output voltage of the system (corresponding to pH) as a function of time.

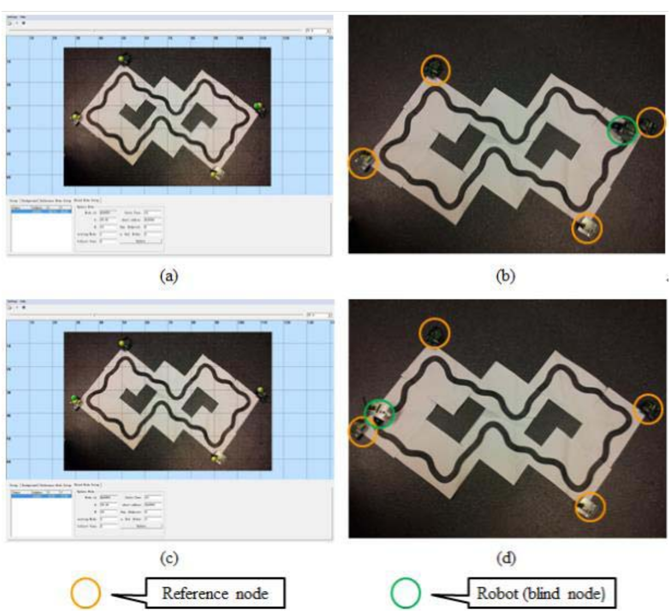

Fig. 9. (a) The GUI software at data monitoring center designed for (b) and (c) for (d).

Following that, the blind node sends out a blast of several 1-hop broadcast messages, and any reference node receiving such a message shall make a running average of the RSSI of the packets received from the targeted blind node. After the broadcast phase, the targeted blind node will send a one-hop unicast message to every reference nodes in radio range requesting the average RSSI calculated during the broadcast blast. The location information of the targeted blind node (the robot position in this test) can then be calculated based on the corresponding physical location information of each reference nodes configured with (X, Y) and RSSI values. When the position of the targeted blind node is calculated, the coordinates of the estimated location can been seen in the GUI software as well as the blind node appearing as a green dot in the background map as shown in Figure 9(a) and (c). The targeted blind node (mobile WSN platform) has been programmed to perform a line tracing exploration strategy, with the real-time estimated location information displayed at the data monitoring centre indicated in Figure 9(a) and (c). When the targeted blind node moves from one reference node (Figure 9(b)) to another (Figure 9(d)), the green dot in the background map of GUI software indicating the targeted blind node moves accordingly as shown in Figure 9(a) and (c) respectively. This positive result illustrates the successful implementation of real-time monitoring and tracking system for wireless mobile platform.

IV. Conclusion and Future Work

This paper has demonstrated the design and implementation of a novel wireless mobile platform which can readily be integrated with both physical and chemical optical fibre sensors and results from a test measurement scenario. In this work, it has been demonstrated with two sensor systems specially designed and implemented, these being representative of both physical and chemical optical fibre sensors, and that a mobile robot could be successfully integrated with the WSN module to form a novel integrated wireless mobile platform for optical fibre-based measurement. To demonstrate the proof of concept in this work, an evaluation of the platform using an optical fibre temperature sensor and pH sensor was undertaken and the location identification of the mobile WSN platform using RSSI localization algorithm has been made. The work carried out has shown positive experimental results and demonstrated clearly the potential for extension to other optical fibre sensor concepts, either FBG-based or indeed using other technologies. The integrated wireless mobile platform designed for optical fibre sensor installation is generic and thus it can be easily adapted to be integrated with an array of different optical fibre sensors for various industrial applications, where flexible mobility, high sensitivity and real-time monitoring are needed. Research is on-going to optimize data processing and robot control algorithms to allow for 'self-correction' for unexpected scenarios, taking full advantages of mesh networking involved and in the deployment of different optical fibre sensors in the platform. This will occur in parallel with the development of more efficient robot exploration strategies and in conducting further practical field tests using different types of optical fibre sensors to improve further the overall performance of the system and thus implement a full autonomous mobile WSN platform for optical fibre sensors.

References

[1] B. Culshaw, "Optical fiber sensor technologies: Opportunities and-perhaps-pitfalls," *J. Lightw. Technol.*, vol. 22, no. 1, pp. 39–50, Jan. 2004.

[2] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," *Comput. Netw.*, vol. 52, no. 12, pp. 2292–2330, Aug. 2008.

[3] E. O'Connell, M. Healy, S. O'Keeffe, T. Newe, and E. Lewis, "A mote interface for fiber optic spectral sensing with real-time monitoring of the marine environment," *IEEE Sensors J.*, vol. 13, no. 7, pp. 2619–2625, Jul. 2013.

[4] G. Tuna, V. C. Gungor, and K. Gulez, "An autonomous wireless sensor network deployment system using mobile robots for human existence detection in case of disasters," *Ad Hoc Netw.*, vol. 13, pp. 54–68, Feb. 2012.

[5] H.-W. Tsai, C.-P. Chu, and T.-S. Chen, "Mobile object tracking in wireless sensor networks," *Comput. Commun.*, vol. 30, no. 8, pp. 1811–1825, Jun. 2007.

[6] S. Fu, Z.-G. Hou, and G. Yang, "An indoor navigation system for autonomous mobile robot using wireless sensor network," in *Proc. Int. Conf. Netw., Sens. Control*, Mar. 2009, pp. 227–232.

[7] B. Zhou, S. Yang, T. Sun, and K. T. V. Grattan, "A novel wireless mobile platform integrated with optical fibre sensors," *Proc. SPIE*, vol. 9157, pp. 1–5, Jun. 2014.

[8] H. J. R. Dutton, *Understanding Optical Communications*. Englewood Cliffs, NJ, USA: Prentice-Hall, 1998.

[9] N. A. Mohammed, T. A. Ali, and M. H. Aly, "Evaluation and performance enhancement for accurate FBG temperature sensor measurement with different apodization profiles in single and quasi-distributed DWDM systems," *Opt. Lasers Eng.*, vol. 55, pp. 22–34, Apr. 2014.

[10] T. Hien Nguyen, T. Venugopalan, T. Sun, and K. T. V. Grattan, "Development of intrinsic optical fiber pH sensors for industrial applications," in *Proc. IEEE Sensors*, Oct. 2009, pp. 89–94.

[11] W. Chen, L. Yua, and Y. Xi, "A review of control and localization for mobile sensor networks," in *Proc. 6th World Congr. Intell. Control Autom.*, Jun. 2006, pp. 9164–9168.

[12] G. Zanca, F. Zorzi, A. Zanella, and M. Zorzi, "Experimental comparison of RSSI-based localization algorithms for indoor wireless sensor networks," in *Proc. RealWSN*, 2008, pp. 1–5.

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